Radiation Physics Note #85

# Dose Estimates at the Beam-On Dose Assessment Facility

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## I. INTRODUCTION

The beam-on dose assessment facility at Fermilab (which used to be the so-called body counter facility) contains both a GM counter (ELRON) and an 8" (diameter) by 2" (thick) NaI scintillation detector. The facility is used to get a preliminary dose estimate of the induced activity in an individual resulting from an accidental exposure in an accelerator produced particle beam. After an initial survey at Fermilab the affected person is to be transported to the more fully equipped whole body counter facilities at Argonne National Laboratory.

This brief note outlines an approximate method to quickly evaluate the radiation dose received by the exposed person. The technique depends upon measurements with both the GM counter and the NaI detector at times of about 30 minutes, but not more than one hour, after irradiation. It is based on measurements made at Brookhaven National Laboratory by Distenfeld, et al.,[1] and at the Lawrence Berkeley Laboratory by Miller and Patterson.[2] These studies were carried out in an enclosure in the AGS experimental area, and in the various particle beams at LBL. They reflect, therefore, the characteristics of the composition and spectra of the radiation fields at these institutions and not necessarily those at Fermilab. The estimates thus must be regarded as preliminary pending further direct beam studies in the Fermilab radiation field environments.

## II. DISCUSSION

The BNL studies[1] were based on the response of a Victoreen 440 ion chamber to the annihilation radiation - 0.511 MeV gammas - that result from the decay of $^{15}O$ ($T_{1/2}\cong 2$ min), $^{13}N$ ($T_{1/2}\cong 10$ min), and $^{11}C$ ($T_{1/2}\cong 20.4$ min), isotopes that are predominant within the first few hours after exposure, from activation of body tissue. Figure 1 shows the Victoreen calibration curve determined in the measurements. The dose estimates presented in Sect. III of this report are based on the use of this calibration curve and measurements with the Elron at the exposed individual's midsection. It relies on the reasonable assumption that the GM counter used at Fermilab responds similarly to the Victoreen ion chamber for 0.511 MeV gamma radiation.

It should be noted that the calibration curve, Fig. 1, is based on measurements at BNL in an approximately constant radiation field, while at Fermilab during fixed-target running periods the beam extracted from the TEVATRON is on for only 23 seconds out of every minute. Thus, any accidental beam-on exposure occurs in a "pulsed" radiation field with a duty factor of only 0.38 (rather than 1). Nevertheless, as shown in the Appendix, this state of affairs does not modify the dose estimates, based on Fig. 1, given in Sect. III.

The LBL results[2] were based on counting the activity in irradiated phantoms with a 3" (diameter) by 3" (thick) NaI scintillation counter. The phantoms were placed in direct contact with the detector, which was set to count all $\gamma$-rays with energy greater than ~0.1 MeV. For direct irradiation in hadron beams, the predominant activity at a time 30 minutes after irradiation was observed to be due to $^{11}C$. The dose equivalent sensitivity (at 30 minutes past irradiation) was, within a factor of two, 176 counts per second (above background) per 25 rem, or 7.04 counts/sec per rem of dose equivalent, for <u>all</u> particle beams at energies between 0.73 and 6 GeV irrespective of beam composition.

At Fermilab, an exposed individual is placed on a cot at a distance of about 1 cm from the 8" x 2" NaI detector. The counting rate within the 0.511 MeV gamma ray photo peak and above a threshold of about 0.1 MeV are both recorded. The absolute efficiencies[3] for 3" by 3" and 8" by 2" NaI detectors are shown in Fig. 2 as a function of the distance between a point source and the detector. The dose estimates given in Sect. III from these measurements are based on the ratio of the 8" x 2" efficiency at 1 cm to that of the 3" by 3" detector (used at LBL) at 0 cm, along with the dose equivalent sensitivity found in the LBL measurements, discussed above. This <u>ratio</u> of point source detector efficiencies is assumed to be valid for thin disk sources as well.

## III. <u>DOSE ESTIMATES</u>

### 1. For the ELRON measurements

From an estimate of the total time of the exposure and the post exposure time before measurement, determine the factor A from Fig. 1. The total dose, in rads, is

$$\text{DOSE} = \text{ELRON Reading (mR/hr)} \times A$$

For example, an accident victim exposed for about 2.5 minutes was monitored with the ELRON after a delay of 30 minutes. The estimated dose is, from Fig. 1, equal to 58 × ELRON Reading (rads).

### 2. For the 8" by 2" NaI Detector

From Fig. 2, the ratio of the efficiency of the 3" by 3" detector at 0 cm (on contact) to that of the 8" by 2" detector at 1 cm is about 1.0. The total dose equivalent, in rem, is

$$\text{DOSE EQUIVALENT} = \frac{N}{(7.04/1.0)} = \frac{N}{7.04}$$

Here N is the net counting rate in counts per sec (gross counting rate minus background counting rate) above the threshold of ~0.1 MeV.

The number of background counts above a 0.1 MeV threshold varies from day to day at the Dose Assessment facility but averages about 6400 counts/min, or 107 counts/sec. Then, the minimum counting rate above background that is significant at the 95% confidence level can be calculated as 187 counts/min, or 3.12 counts/sec. With a sensitivity of 7.04 counts/sec per rem (from above) for the 8" by 2" detector, the minimum detectable dose equivalent is about 0.4 rem.

## IV. CONCLUSION AND CAVEATS

It must be emphasized again that these dose estimates are preliminary. Since they are based on data obtained at other laboratories - at considerably lower beam energies and in radiation fields that may be quite different from those at Fermilab - large uncertainties (even larger than the factors of two estimated in both BNL and LBL reports) may exist. It is important therefore to perform measurements with phantoms in Fermilab fields.

Finally, it is appropriate to issue specific warnings as regards, particularly, the techniques employed in the BNL studies.

1. The tissue equivalent ion chamber used for the "true" dose determination was a 25 $cm^3$ air filled cavity surrounded by 6 mm thick Shonka plastic walls. Hadronic and electromagnetic cascades arising from incident high-energy hadrons are probably not fully developed in such thin walls so that the chamber might significantly underestimate the maximum dose to tissue that would occur at greater depths. Nor was the chamber calibration technique specified.

2. A second ion chamber containing a 3 mm polyethylene liner surrounding an ethylene cavity was exposed along with the Shonka plastic chamber, and gave a dose 40% larger than the "true" dose measurement.

3. The neutron spectrum at the measurement position was not determined. The studies were, in fact, done in an average loss condition in the enclosure and not in the direct beam.

4. Film badge readings were lower by factors of 3-4 compared to those from TLD-700s. (This may indicate a large ambient thermal neutron flux at the measurement position, since the over response of the TLD-700 could arise from thermal neutron interactions in the $^6$Li present in the normal Li abundance.)

## REFERENCES


1. C.H. Distenfeld, R.D. Colvett, and J.A. Ash, Evaluation of Accidental Exposure to Accelerator Personnel, Health Physics & Safety Division Informal Report, Brookhaven National Laboratory, Upton, NY (April 14, 1973).

2. A.J. Miller and H.W. Patterson, "Measurement of Induced Activity to Estimate Personnel Radiation Exposures Received from Accelerator Beams," Health Phys. 23, 671 (1972).

3. The calculations were based on expressions discussed in: S.H. Vegors, L.L. Marsden, and R.L. Heath, Calculated Efficiencies of Cylindrical Radiation Detectors, IDO-16370, Phillips Petroleum Co., Idaho Falls, Idaho (1958).

4. J.D. Cossairt, Usage of Chipmunks and Scarecrows in TEVATRON Radiation Fields, Fermilab Rad. Phys. Note #44 (1984).


## FIGURES

1. Calibration curve to use for dose estimate with the Elron. From Fig. 5 in Ref. 1.

2. <u>Twice</u> the absolute efficiency as a function of distance from a point source for 8" by 2" and 3" by 3" NaI detectors.

## APPENDIX

In the Appendix to Ref. 1, Distenfeld, et al., show that the calibration curve, Fig. 1 in the present report, is constructed by use of the equation

$$A = \frac{k t_a}{f(t_a, t_d)} \quad , \tag{A.1}$$

calculated for various irradiation and post irradiation times $t_a$ and $t_d$, respectively. Here k=0.32, and with decay constants $\lambda$=0.347 min$^{-1}$ for $^{15}O$, $\lambda$=0.069 min$^{-1}$ for $^{13}N$, and $\lambda$=0.034 min$^{-1}$ for $^{11}C$, $f(t_a,t_d)$ is given by

$$f(t_a,t_d) = 0.44\left(1-e^{-.347t_a}\right)e^{-.347t_d} + 0.21\left(1-e^{-.069t_a}\right)e^{-.069t_d} + 0.35\left(1-e^{-.034t_a}\right)e^{-.034t_d} \quad . \tag{A.2}$$

For pulsed beams with an irradiation time of $t_s$ ("spill time") during each acceleration cycle of time $t_b$, Cossairt[4] has shown (in a different connection - on the usage of Chipmunks in pulsed radiation fields) that the buildup of activity (or, charge) can be written as

$$R = \left(1-e^{-\lambda t_s}\right)\left(1+e^{-\lambda t_b}+e^{-2\lambda t_b}+e^{-3\lambda t_b}+ \ldots x e^{-(n-1)\lambda t_b}\right) ,$$

where n is the number of "spills." This is a geometric series with a constant ratio of $e^{-\lambda t_b}$. The sum after n-terms is given by

$$R = \frac{1-e^{-\lambda t_s}}{1-e^{-\lambda t_b}}\left\{1-\left(e^{-\lambda t_b}\right)^n\right\} \quad . \tag{A.3}$$

Using Eq. (A.3), Eq. (A.2) can be modified for pulsed fields as

$$\begin{aligned} f = {} & 0.44\left(\frac{1-e^{-.347t_s}}{1-e^{-.347t_b}}\right)\left\{1-\left(e^{-.347t_b}\right)^n\right\}e^{-.347t_d} \\ & + 0.21\left(\frac{1-e^{-.069t_s}}{1-e^{-.069t_b}}\right)\left\{1-\left(e^{-.069t_b}\right)^n\right\}e^{-.069t_d} \\ & + 0.35\left(\frac{1-e^{-.034t_s}}{1-e^{-.034t_b}}\right)\left\{1-\left(e^{-.034t_b}\right)^n\right\}e^{-.034t_d} \quad . \end{aligned} \tag{A.4}$$

At Fermilab with $t_s$ = 0.38 min and $t_b$ = 1 min, Eq. (A.4) becomes

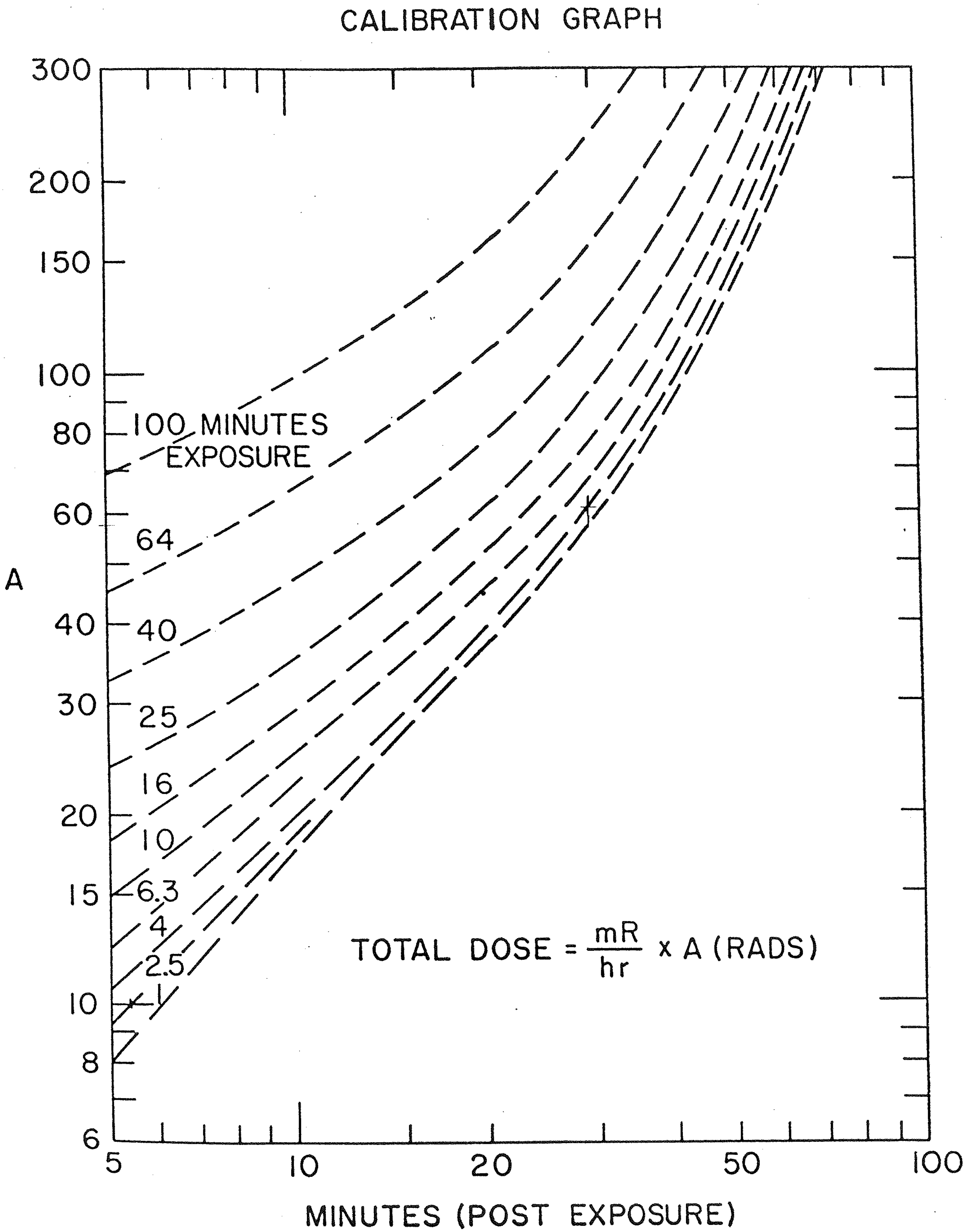
$$\begin{aligned} f_{FNAL} = {} & 0.185 \ (1-0.707^n)e^{-.347t_d} \\ & + 0.0815 \ (1-0.933^n)e^{-.069t_d} \\ & + 0.134 \ (1-0.967^n)e^{-.034t_d} \quad . \end{aligned} \tag{A.5}$$

By use of Eq. (A.5), $f_{FNAL}$ was evaluated for values of n from 1 to 10 and for post exposure times $t_d$ of 5 to 40 minutes, and compared to the quantity $f_{BNL}$ (Eq. A.2) for irradiation times of 1 to 10 minutes and the same post irradiation times $t_d$. In all cases, the ratio $f_{BNL}/f_{FNAL}$ is very closely equal to 2.6. Since, at Fermilab, the total irradiation time is about 0.38 times the irradiation time at BNL, the value of A for Fermilab exposures is by use of Eq. (A.1), equal to 0.38 times $f_{BNL}/f_{FNAL}$. Thus,

$$A_{FNAL} = 0.38 \times 2.6 \times A_{BNL} \simeq A_{BNL}. \qquad \text{(A.6)}$$

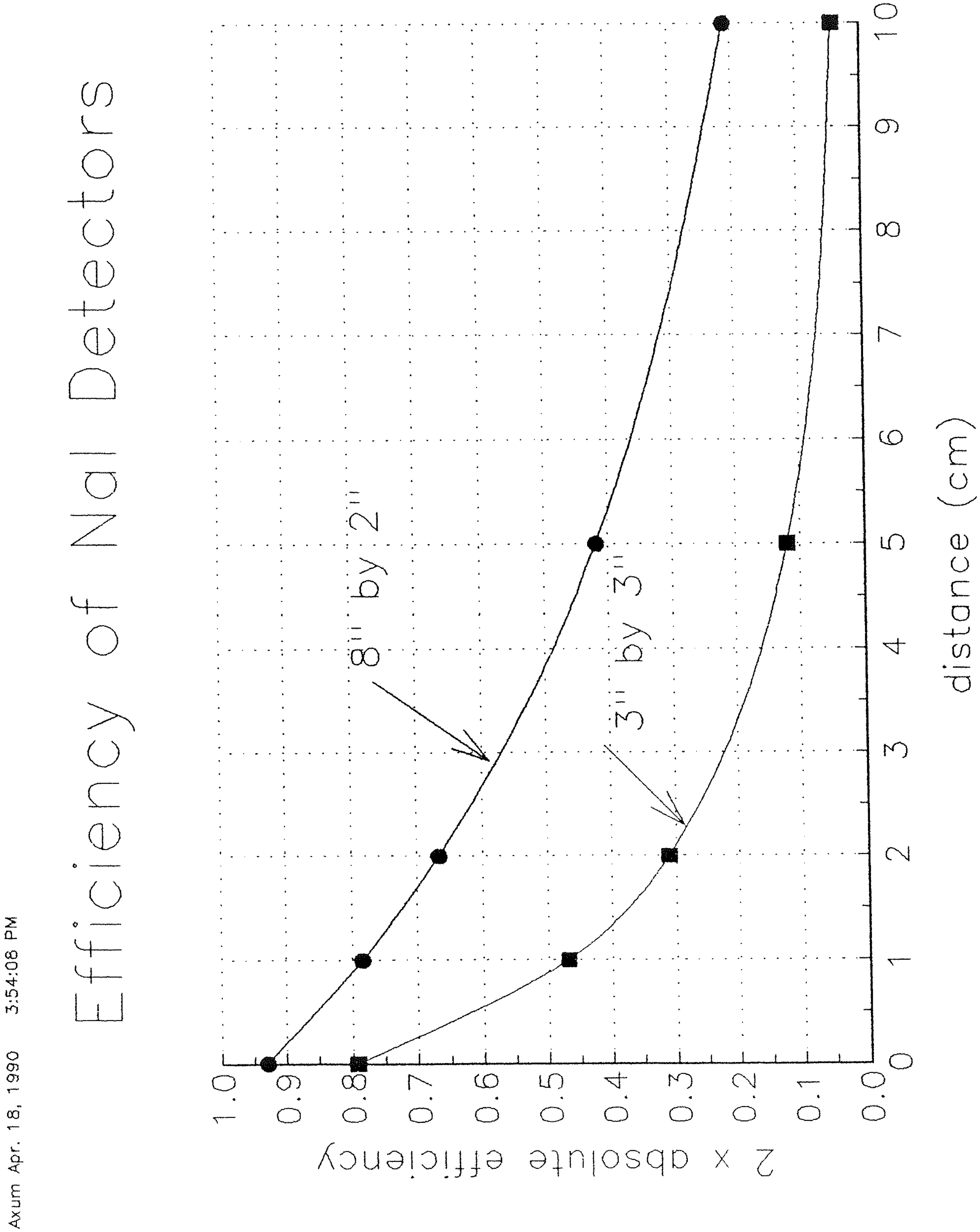
Fig. 1 can therefore be used without modification to estimate the dose, as discussed in Sect. III.

Figure 1



CALIBRATION GRAPH
300
200
150
100
80
60
A
40
30
20
15
10
8
6
100 MINUTES
EXPOSURE
64
40
25
16
10
6.3
4
2.5
1
TOTAL DOSE = $\frac{mR}{hr}$ x A (RADS)
5
10
20
50
100
MINUTES (POST EXPOSURE)

**Figure 2**


Axum Apr. 18, 1990 3:54:08 PM
Efficiency of NaI Detectors
8" by 2"
3" by 3"
2 x absolute efficiency
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
distance (cm)
0
1
2
3
4
5
6
7
8
9
10